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Title: Fissile Material Outside of Reactors and the Los Alamos Benchmark Suite

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Abstract for flyer:

This seminar will present two studies related to fissile material outside of reactors. First, an optimization methodology will be presented that identifies used fuel loading configurations in dry cask storage to minimize the number of casks needed, their average initial heat load, and the time at which they meet transportation requirements. This method was implemented in a new tool for integration with the unified database from the Used Fuel Systems group at Oak Ridge National Laboratory. Its performance was evaluated against a utility-chosen loading strategy and was shown to perform well. The second study will focus on current efforts at Los Alamos National Laboratory to improve the modeling of critical benchmark experiments. This modeling forms the basis for criticality safety and nuclear data validations. Over one thousand individual MCNP input files have been reviewed and are currently being revised and added to the Los Alamos Benchmark Suite. The performance of these models will be compared with those from Oak Ridge National Laboratory and the Institute for Radiological Protection and Nuclear Safety.

Fissile Material Outside of Reactors and the Los Alamos Benchmark Suite

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she/her/hers

March 30, 2021

About Me

- **Los Alamos National Laboratory**
  - Criticality Safety Analyst
  - Lead Whisper SQA
- **Paul Scherrer Institut**
  - Fulbright Fellowship
  - European Lead-cooled System
- **Texas A&M University**
  - B.S., M.S., & Ph.D. in Nuclear Engineering
  - Internships at Fermilab, LLNL, ORNL

Top: Basel, Switzerland
Bottom: Albuquerque, New Mexico

Used Nuclear Fuel Management

Optimization of Dry Cask Loading Patterns with the Used Fuel Systems Group at Oak Ridge National Laboratory

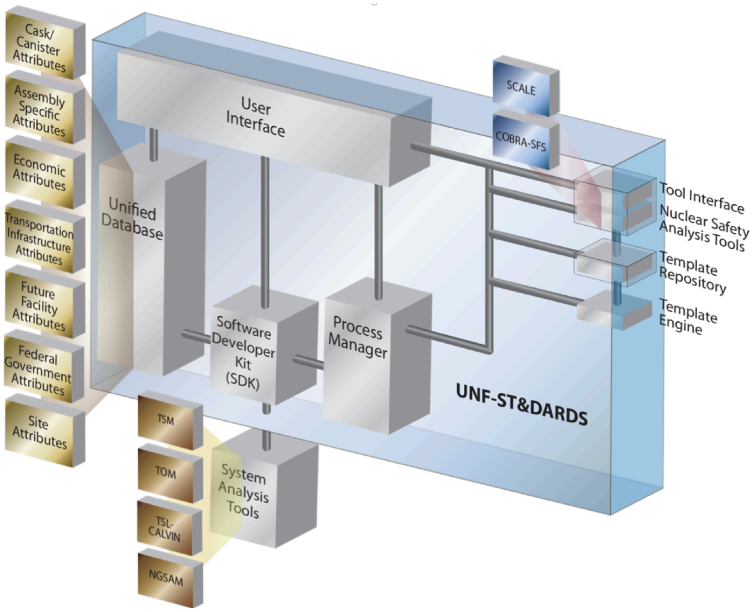


Fig. courtesy of Oak Ridge National Laboratory, US Dept. of Energy.

UNF-ST&DARDS

- Python Optimization Tool integrated with UNF-ST&DARDS
- MySQL database by the Used Fuel Systems group at ORNL
- Contains:
  - fuel assembly design data and discharge information
  - reactor operation data
  - cask design and loading data
  - infrastructure data

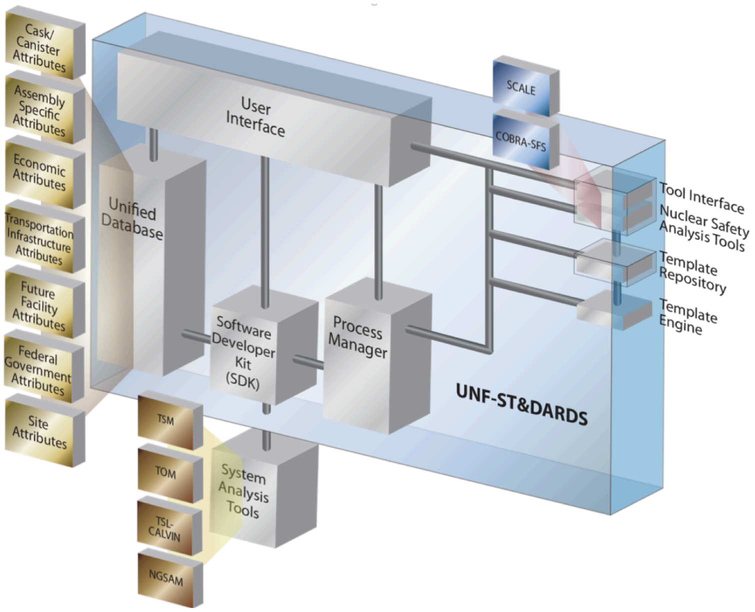


Fig. courtesy of Oak Ridge National Laboratory, US Dept. of Energy.

The Dry Cask Loading Problem

Objectives

Minimize:

- Number of casks
- Average initial heat of each cask at loading time
- Maximum time to transport

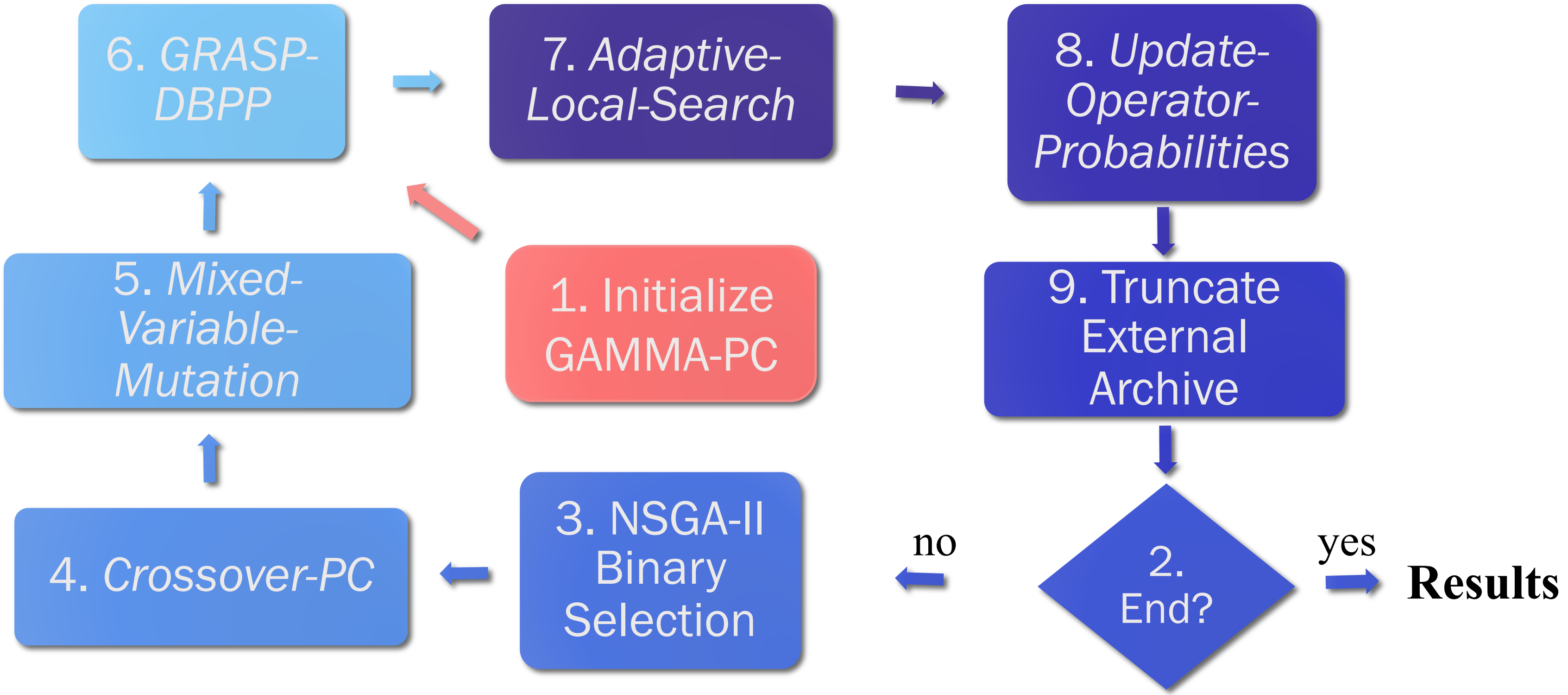
Constraints

- Physicality constraints
- Assembly selection constraints
- Spent fuel pool constraints
- Operational constraints

Loading Matrix	Casks Used Array	Transfer Time Array	Theoretical Maximum
$x = \begin{bmatrix} x_{1,1} & \cdots & x_{1,N} \\ \vdots & \ddots & \vdots \\ x_{\bar{M},1} & \cdots & x_{\bar{M},N} \end{bmatrix}$	$y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_{\bar{M}} \end{bmatrix}$	$t_{fill} = \begin{bmatrix} t_{fill,1} \\ t_{fill,2} \\ \vdots \\ t_{fill,\bar{M}} \end{bmatrix}$	$\bar{M} = \left\lceil \frac{N}{0.75 C_{cask}} \right\rceil$

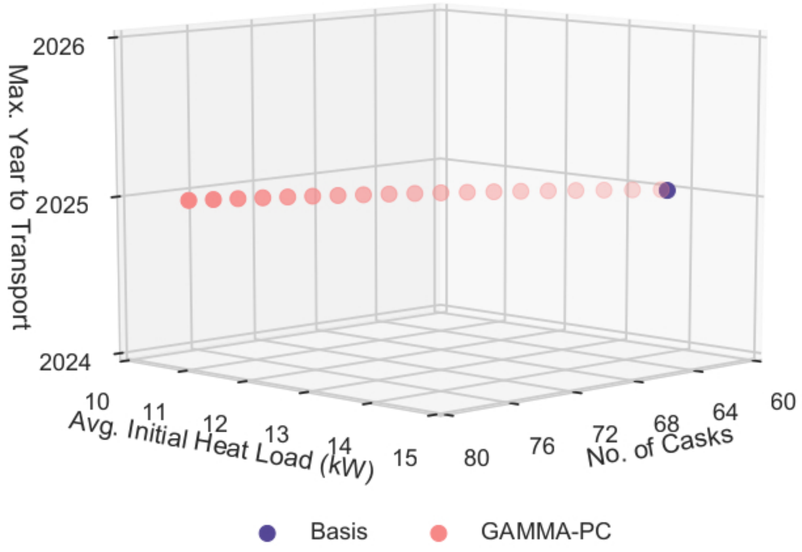
GAMMA-PC

GRASP-enabled adaptive multiobjective memetic algorithm with partial clustering



Zion Nuclear Power Plant

Problem Parameters	
Cask system	NAC MAGNASTOR
C_{cask}	37
$H_{s,max}$ [kW]	35.5
$H_{t,max}$ [kW]	23.0
$BU_{s,max}$ [GWd/MTU]	60.0
$BU_{t,max}$ [GWd/MTU]	70.0
No. of Casks Needed:	
Lower Bound	61
Maximum $\bar{M}$	81
Function Evaluations	20,000
Testing Set	ZionSolutions loading



Objective vectors of solutions.

Zion – Selected Solutions

- Basis:

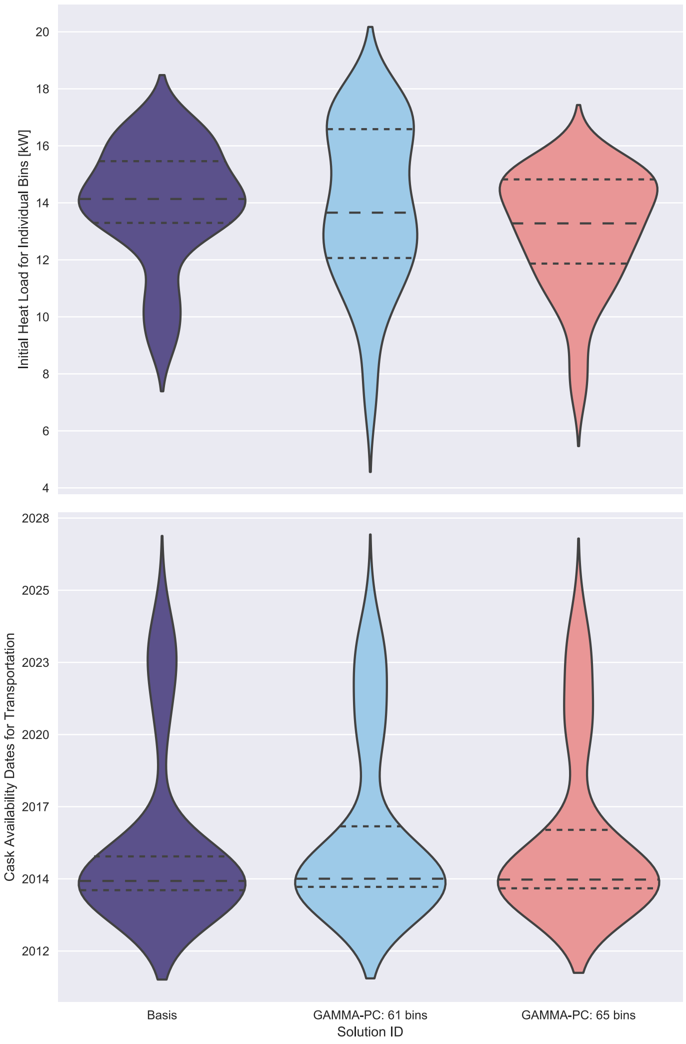
$$F\text{=(61, 13.94, 2025)}$$

- Recommended:

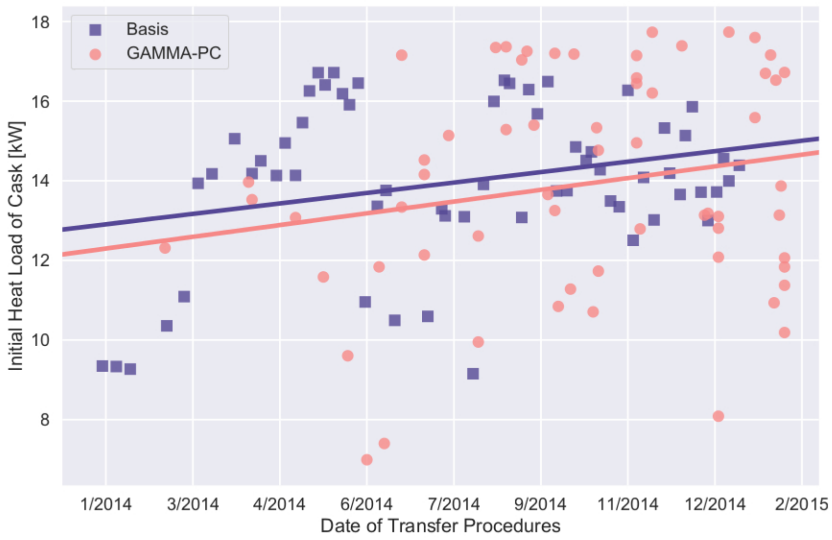
$$F\text{=(61, 13.84, 2025)}$$

- Alternate:

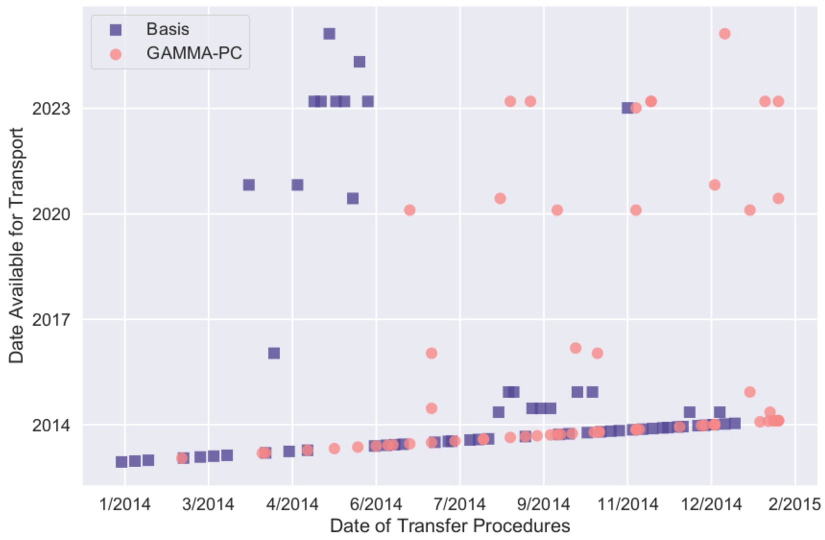
$$F\text{=(65, 13.00, 2025)}$$



Zion – Individual Cask Characteristics



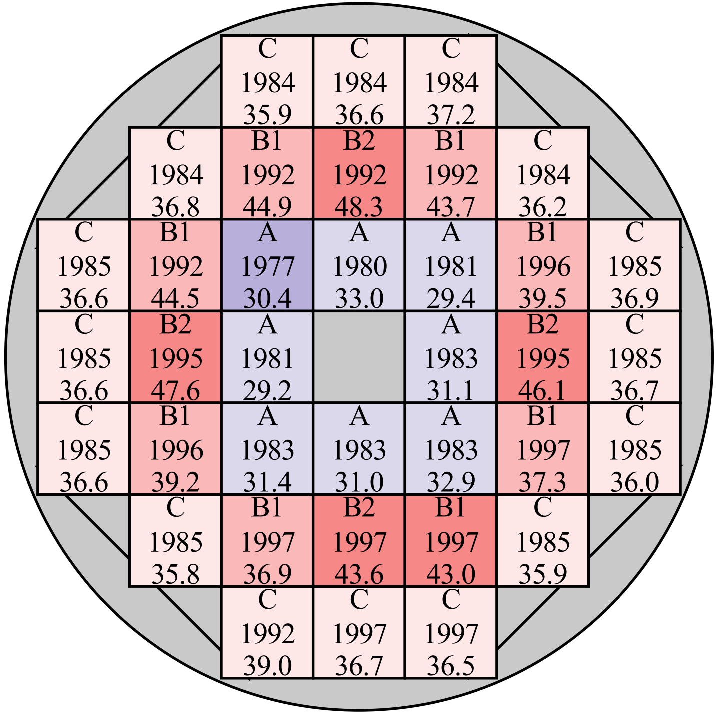
Initial Heat Load



Date Available for Transport

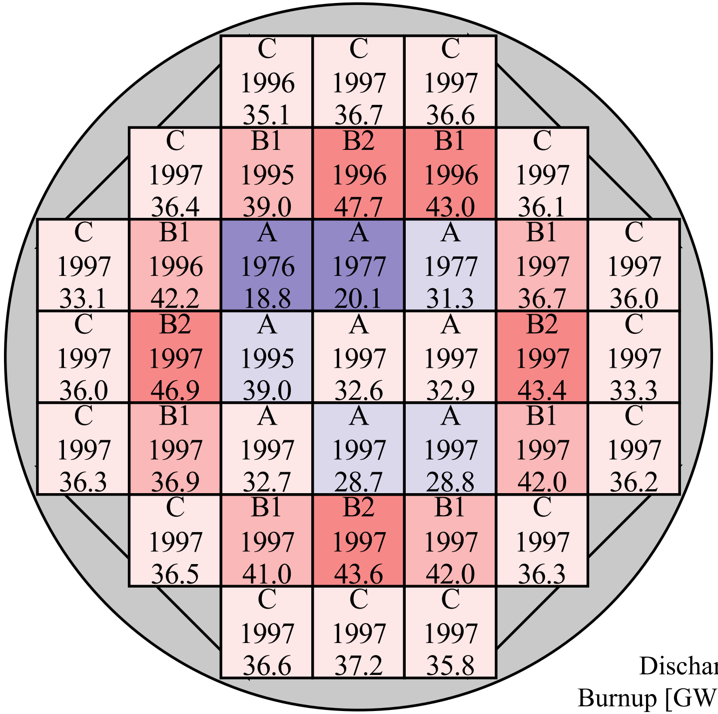
Zion Assembly Thermal Limits by Region

A: 0.487 kW | B1: 1.235 kW | B2 : 1.71 kW | C: 0.788 kW



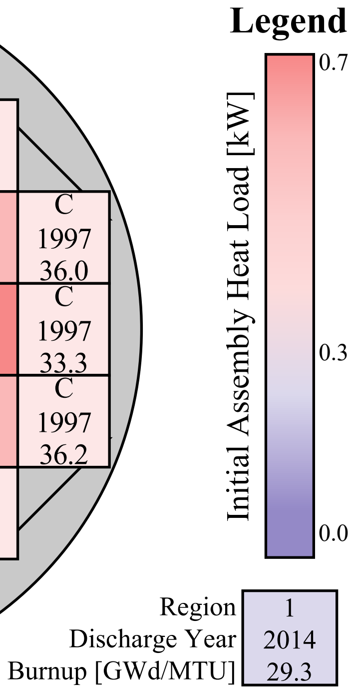
Basis

$t_{fill} = May\ 2014;\ q_0 = 16.72\ kW$



GAMMA-PC

$t_{fill} = Jan.\ 2015;\ q_0 = 17.74\ kW$



General Trends in Test Cases

- GAMMA-PC performs well, producing diverse solutions that dominated the testing sets.
- Improvement mainly achieved for average initial heat load.
- Maximum time to transport was sensitive to individual assembly characteristics.
  - Driven by nuclear criticality safety
- The Zion test case highlighted the variability of cask characteristics.

Nuclear Criticality Safety

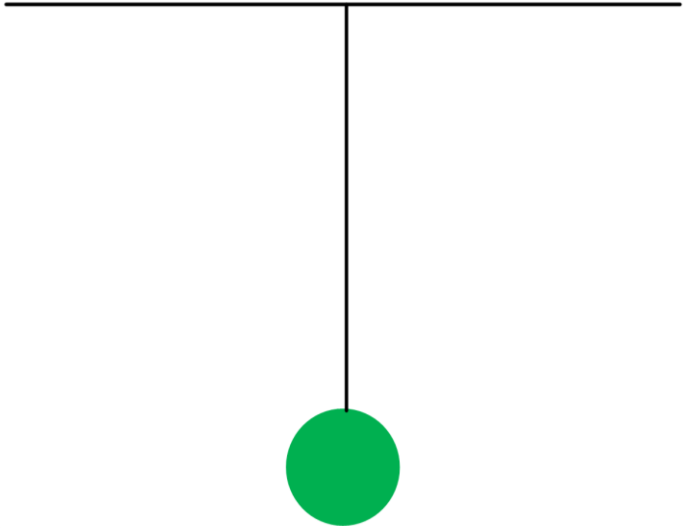
Before a new operation is begun, or before an existing operation is changed, it shall be determined that the entire process will be subcritical under both normal and credible abnormal conditions.

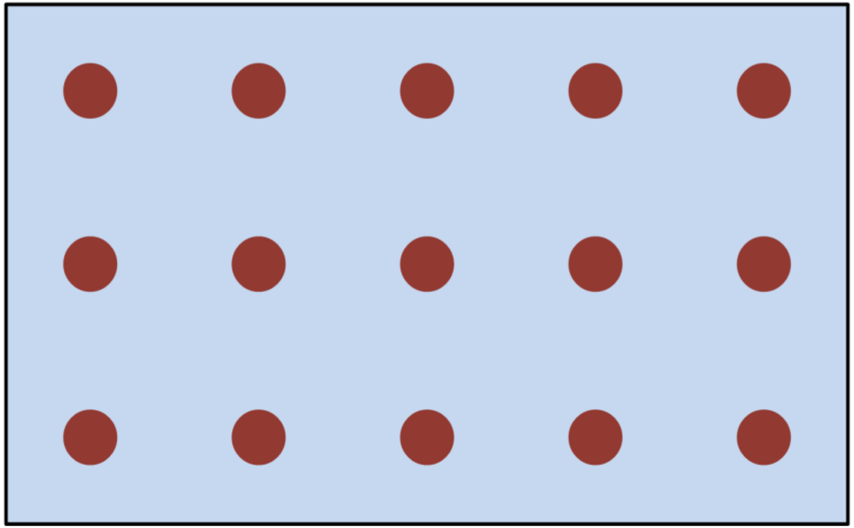
- ANSI/ANS-8.1

Which system has a smaller safety margin?

6kg α-phase ^{239}Pu
Sphere
$k_{eff} = 0.84$

Natural U rods
In Water
$k_{eff} = 0.97$

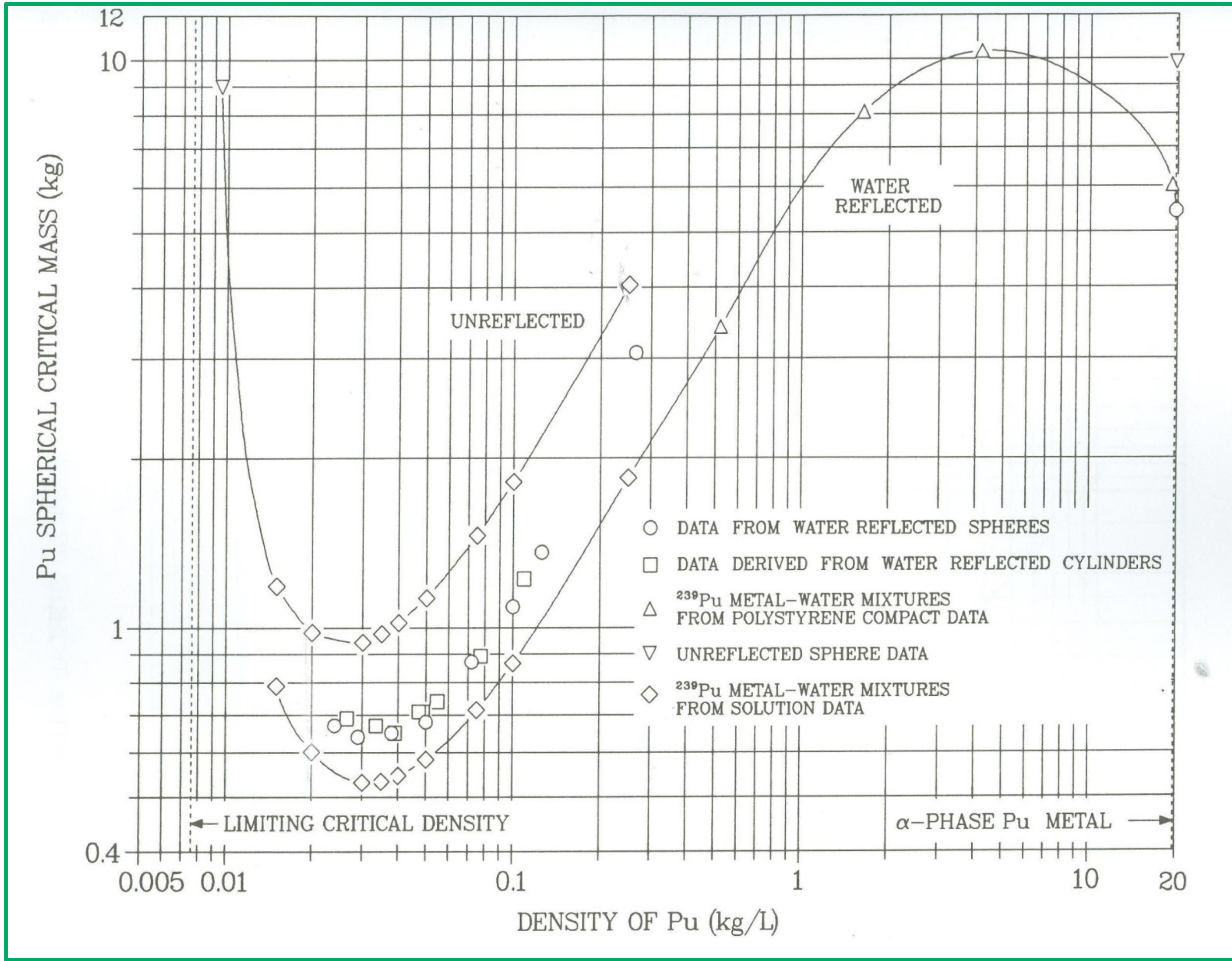




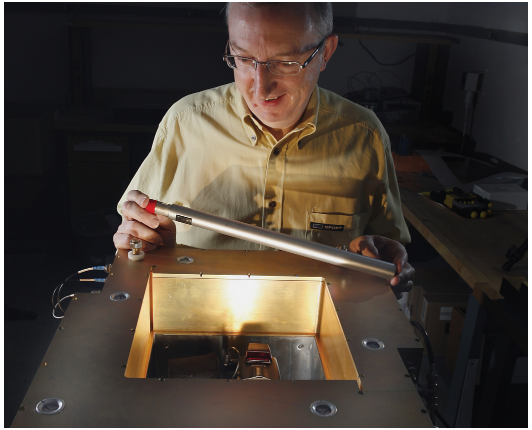
Borrowed from NCSP, Module 1, "Nuclear Criticality Safety Fundamentals"

Daily Activities

- Evaluating fissionable material operations
- Procedure reviews
- Operations reviews
- Responding to potential process deviations
- Nuclear criticality safety training



Supporting Fissionable Material Operations



Martyn Swinhoe, N-1, working with a neutron detector

Science & Technology Operations

- Detector Development
- IAEA Training Classes
- Uranium Processing/Machining

Dali Yang at work in her laboratory

Chemistry & Metallurgy Research

- Analytical Chemistry
- Nondestructive Assessments
- De-inventory Activities

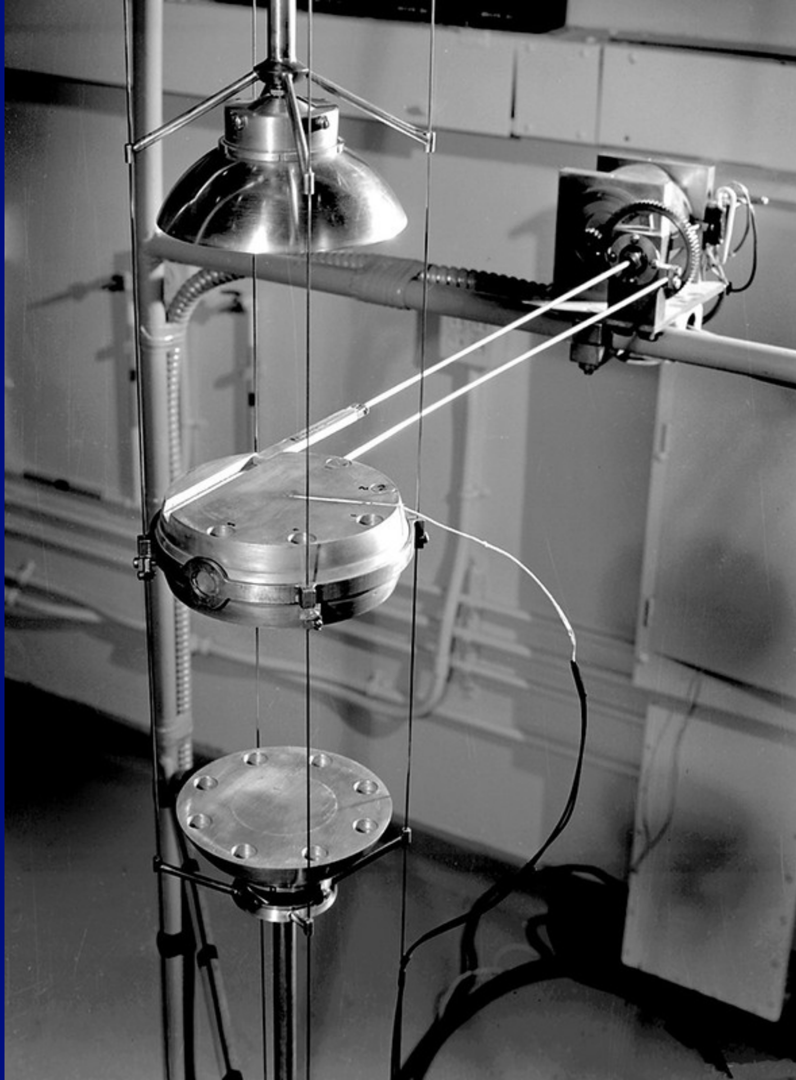
DOE Secretary Spencer Abraham on his first visit to LANL

Plutonium Facility

- Pit Manufacturing
- Plutonium Recovery

The Los Alamos Benchmark Suite

- Whisper 1.1.0 Software Quality Assurance
- Review and revision of MCNP benchmark input files
- Benchmark Intercomparison Project



ANSI/ANS-8.24

- **ANS-8.24**: Validation of Neutron Transport Methods for Nuclear Criticality Safety Calculations
- *…in accordance with a site-specific software quality assurance program…*

$$USL = 1.0 + Bias - Bias\ Uncertainty - MoS - AoA$$

  - $\boldsymbol{MoS}$: margin of subcriticality
  - $\boldsymbol{AoA}$: additional margin to account for application outside of the "Area of Applicability"

A Very Brief Introduction to Whisper

- **MCNP** determines sensitivity profiles to characterize the neutronics of an application or benchmark.

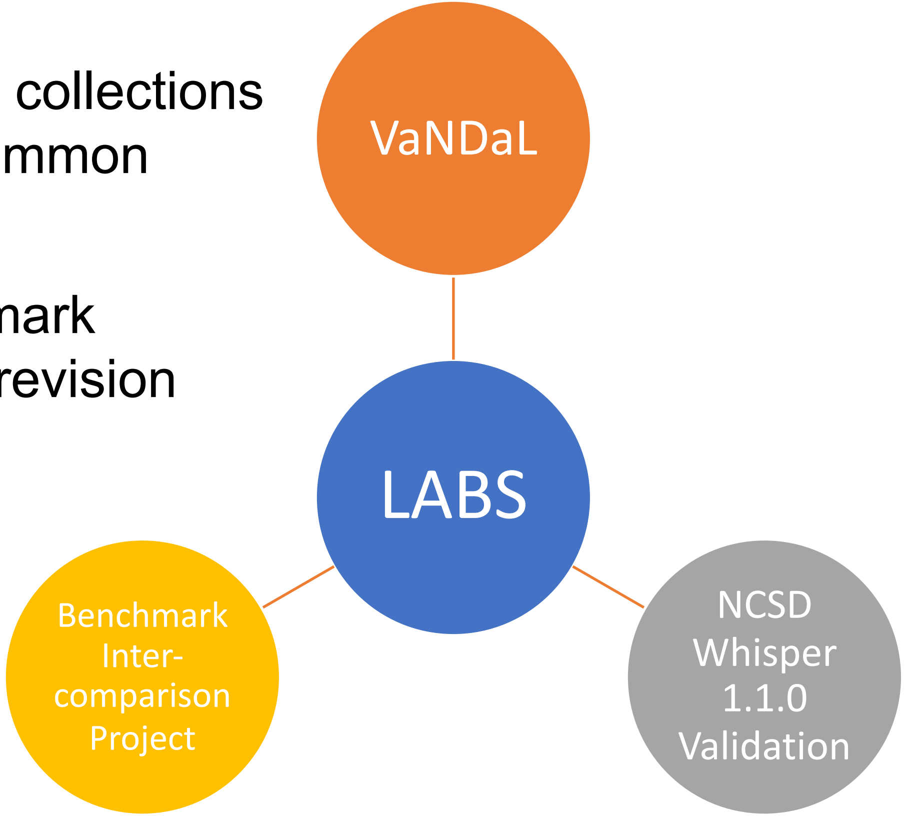
$$S(energy, reaction, isotope) = \frac{(dk/k)}{(d\sigma/\sigma)}$$

- **Whisper** uses sensitivity profiles & data covariances to select benchmarks and to determine bias, bias-uncertainty, & margin of subcriticality to set the USL.

- Experimental Models drawn from the International Handbook of Evaluated Criticality Safety Benchmark Experiments.

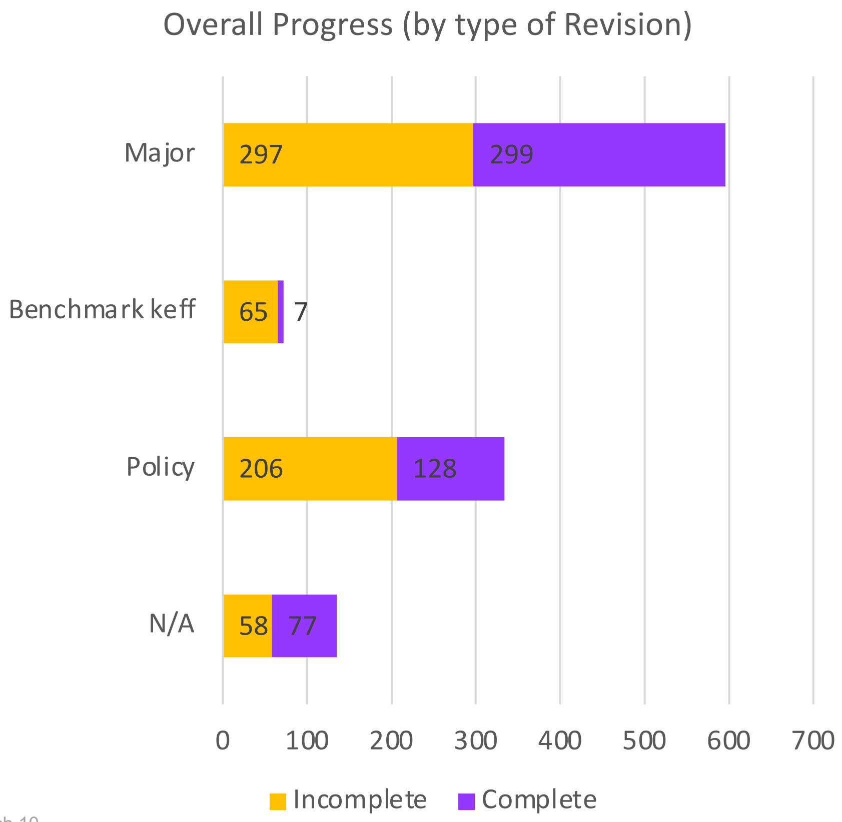
Los Alamos Benchmark Suite

- Multiple MCNP critical benchmark collections at LANL are believed to have a common origin
- LABS – effort to centralize benchmark models, implement formal review/revision process
- Initialized w/ Whisper 1.1.0 Suite
- Reviews completed under NCSD Whisper 1.1.0 SQA



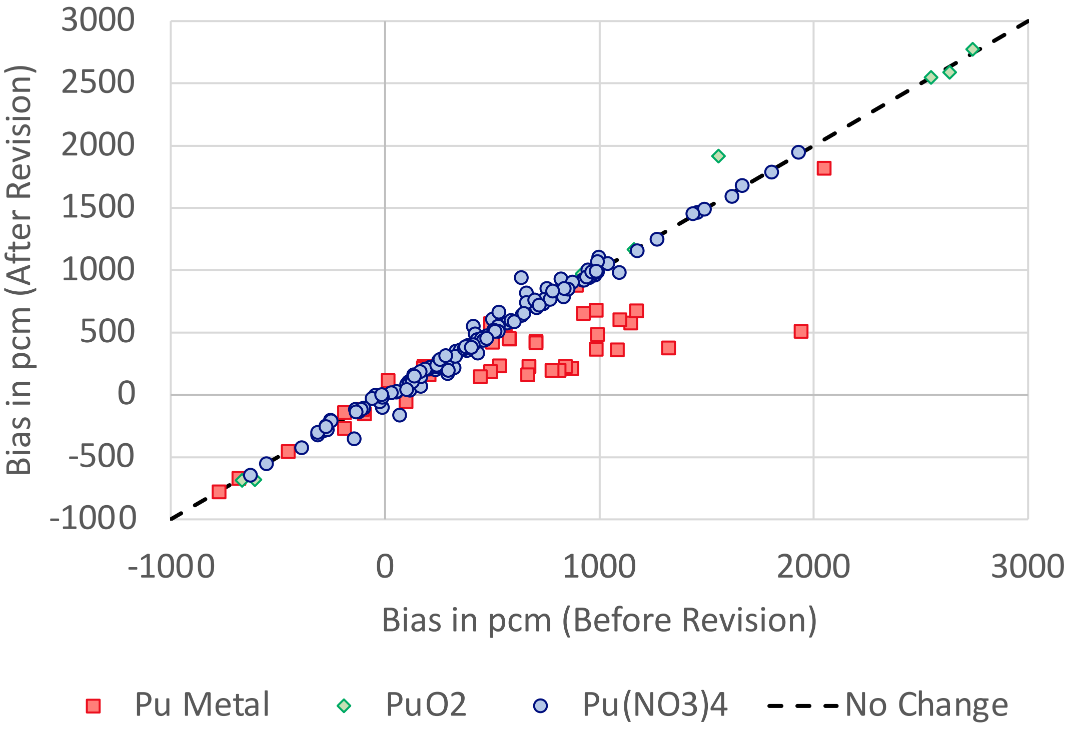
Benchmark Reviews

- Two-person reviews on every input file in Whisper Suite
- Reviews began 12/2016, **completed** 09/2020
  - HMF-077 in Whisper Suite did not align with ICSBEP Handbook (8 cases)
  - Handbook example input files reviewed for this benchmark (3 cases)
  - 5 additional cases reviewed for ICT-002
  - This would keep the total cases at **1101**



Completion Status as of March 10, 2021

LABS – Pu Revisions



Top 12 Largest Changes

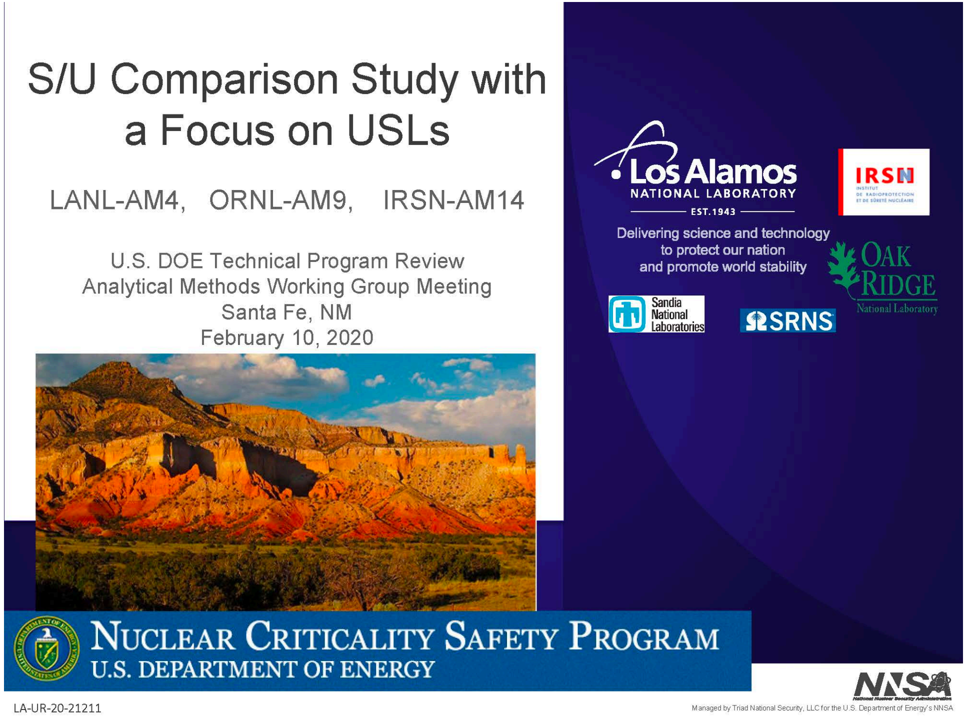
	Change in Bias (pcm)	Combined Error
pu-met-fast-042-001.i	-1430	110
pu-met-fast-042-002.i	-943	106
pu-met-fast-042-003.i	-724	106
pu-met-fast-042-004.i	-656	113
pu-met-fast-042-008.i	-619	101
pu-met-fast-042-005.i	-615	105
pu-met-fast-042-007.i	-612	106
pu-met-fast-042-009.i	-583	102
pu-met-fast-042-010.i	-568	106
pu-met-fast-042-013.i	-505	100
pu-met-fast-044-003.i*	-500	14
pu-met-fast-042-011.i	-497	104

*Change in benchmark k_{eff} value

What's after Whisper 1.1.0?

- OECD-NEA SG45 (VaNDaL) MCNP inputs are available to us
  - These represent ~3500 input files
  - There is some overlap with LABS
- Keep LABS up to date with ICSBEP
  - New LANL benchmarks: work with NEN-2
  - New external benchmarks need to be modelled
  - Tracking revisions (e.g. 2020 revision of PMF1-S)

Benchmark Intercomparison Project (LANL, ORNL, and IRSN)



Comparison of Small Set of Benchmark Problems

- **HEU-MET-FAST-013**: sphere of highly enriched uranium reflected by steel
- **HEU-SOL-THERM-001-008**: bare cylinder partially filled by uranium nitrate solution
- **PU-MET-FAST-022**: bare Pu metal system
- **PU-SOL-THERM-001-001**: water reflected tank filled with plutonium nitrate (4.6% ^{240}Pu)

Adapted from LA-UR-20-21211

Potential Differences in USL

- Benchmark collection and selection (GLLS, expert, c_k)
- Method of calculating bias and bias uncertainty (EVT, USLSTATS, GLLSM)
- Calculated k-eff and uncertainty values (MCNP6, SCALE, MORET)
- Sensitivity profile energy groups
- MOS included in USL?

Adapted from LA-UR-20-21211

Methods

	LANL	ORNL	IRSN
Code	MCNP6.2/ Whisper-1.1	SCALE6.2.2/ USLSTATS	MORET5.D.1/ MACSENS
Benchmarks	1088	428	1566
Statistical Analysis Method	EVT	USLSTATS	GLLSM
Covariance Data	BLO,44g	SCALE6.2.3, 252g	SCALE6.2, 44g

Adapted from LA-UR-20-21211

Difference in calculational margins

	LANL → ORNL	LANL → IRSN	ORNL → IRSN
HEU-MET-FAST-013	0.3%	0.1%	0.4%
HEU-SOL-THERM-001-008	1.9%	3.0%	2.6%
PU-MET-FAST-022	0.9%	1.0%	0.03%
PU-SOL-THERM-001-001	0.4%	1.0%	0.6%

Adapted from LA-UR-20-21211

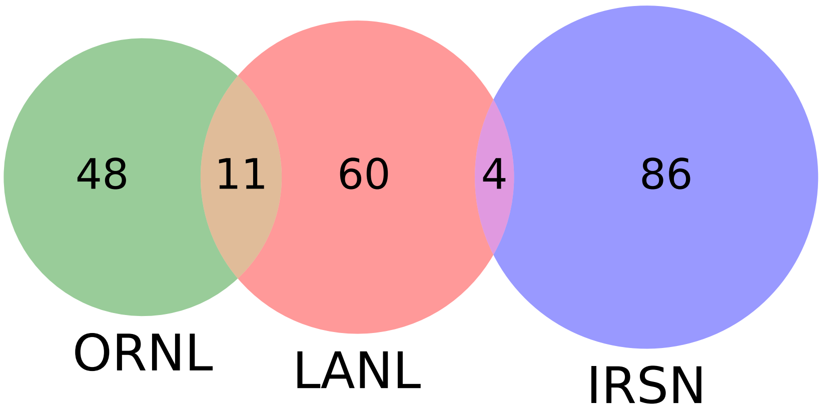
HEU-MET-FAST-013 Results

	LANL	ORNL	IRSN
Bias	-0.0057	-0.0035	-0.0012
Bias Uncertainty	0.0039	0.0090	0.0077
1 - CM	0.9904	0.9875	0.9911
USL	0.9840	User-defined MoS	User-defined MoS

Adapted from LA-UR-20-21211

HEU-MET-FAST-013 Results

- Higher LANL Bias
  - probably due to HMF-084-005, HMF-007-032
- Lack of overlap in benchmark sets unclear



Adapted from LA-UR-20-21211

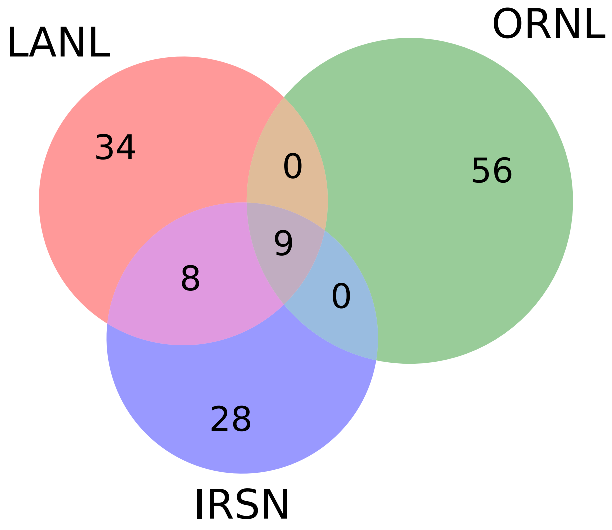
HEU-SOL-THERM-001-008 Results

	LANL	ORNL	IRSN
Bias	-0.0146	-0.0042	0
Bias Uncertainty	0.0173	0.0095	0.0026
1 - CM	0.9680	0.9863	0.9974
USL	0.9616	User-defined MoS	User-defined MoS

Adapted from LA-UR-20-21211

HEU-SOL-THERM-001-008 Results

- Higher LANL bias & bias uncertainty due to HCT-002
- ORNL benchmark set included HST-028, HST-029, HST-030 from VALID & chosen with high c_k
  - not in LANL library



Adapted from LA-UR-20-21211

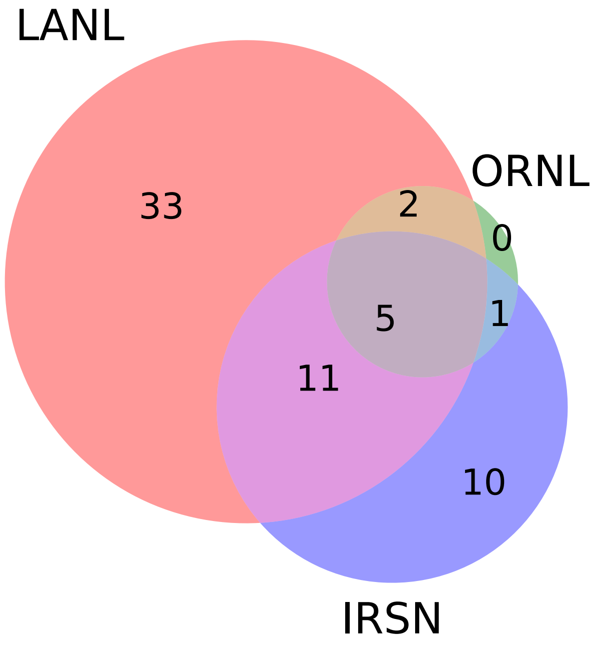
PU-MET-FAST-022 Results

	LANL	ORNL	IRSN
Bias	-0.00857	0	0
Bias Uncertainty	0.00568	0.0050	0.0047
1 - CM	0.9857	0.9950	0.9953
USL	0.9791	User-defined MoS	User-defined MoS

Adapted from LA-UR-20-21211

PU-MET-FAST-022 Results

- Higher LANL bias & bias uncertainty due to PMF-042
- Why wasn't PMF005 chosen by LANL?
  - W elastic and inelastic scatter, sensitivity ~e-02
  - Whisper did choose MMF005, also with W, sensitivity < ~e-05



Adapted from LA-UR-20-21211

PU-MET-FAST-022 Results (at 95%, if all benchmarks match)

	LANL	ORNL
Bias	-0.00325	0.00110 (0)
Bias σ	0.0028	0.00500
MOS_{ND}	0.00126	-
1-CM	0.9940	0.9950
USL	0.9877	0.9950

* Whisper non-coverage penalty MOS=0.03074 excluded

Adapted from LA-UR-20-21211

PU-MET-FAST-022 Results (at 95%, if all benchmarks match)

c_k	LANL Benchmark	ORNL Benchmark	c_k
0.9993	PMF-001-001	PMF-001-001	0.9983
0.9954	PMF-024-001	PMF-024-001	0.9865
0.9952	PMF-023-001	PMF-023-001	0.9813
0.9918	PMF-025-001	PMF-005-001	0.9422
0.9747	PMF-018-001	PMF-025-001	0.8951
0.9644	PMF-008-001	PMF-002-001	0.8915
0.9574	PMF-002-001	PMF-018-001	0.8829
0.6531	PMF-005-001	PMF-008-001	0.8040

$c_k = 0.9127$ w/o W

Adapted from LA-UR-20-21211

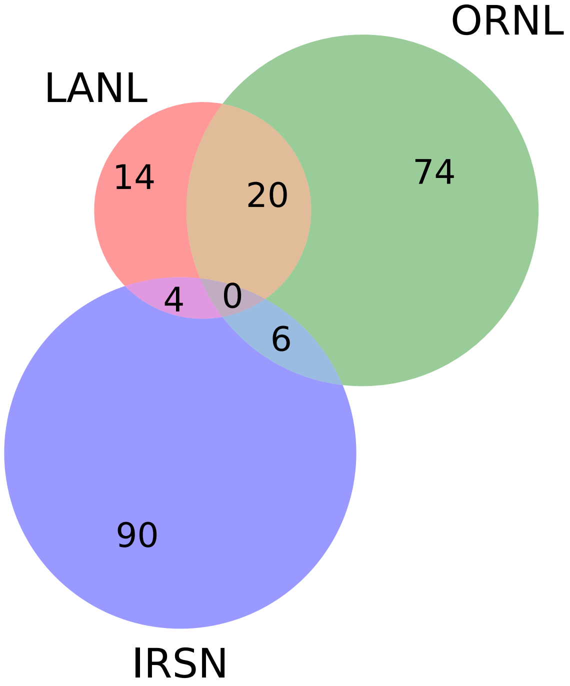
PU-SOL-THERM-001-001 Results

	LANL	ORNL	IRSN
Bias	-0.00597	0	0
Bias Uncertainty	0.00829	0.0105	0.00434
1 - CM	0.9857	0.9895	0.9957
USL	0.9797	User-defined MoS	User-defined MoS

Adapted from LA-UR-20-21211

PU-SOL-THERM-001-001 Results

- Higher LANL bias & bias uncertainty due to PST-010-001
- Overall Results: ΔCM 0.1 % - 3.0%



Adapted from LA-UR-20-21211

Summary

- GAMMA-PC is a memetic algorithm designed for the dynamic combinatorial loading problem.
- The primary goal of a nuclear criticality safety program is to prevent criticality accidents for all credible scenarios.
- LABS is a collaboration of NCS, MCNP, Nuclear Data teams to build a high-quality LANL benchmark suite.

"Veronika Mocko conducting processing efforts on PET isotope"
By Los Alamos National Laboratory

Conclusion

- **GAMMA-PC:** produced an adaptable mathematical framework for the dry cask loading problem. Tool is being submitted to RSICC.
- **LABS:** better quality benchmarks will improve the understanding of bias in MCNP and will help reduce confounding variables to understand differences between codes.

"National Security Sciences Building (NSSB)" by Los Alamos National Laboratory

Thank you! Questions?

- Contact Information:

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- Thanks for GAMMA-PC: US Department of Energy, Office of Nuclear Energy, contract number DE-AC05-00OR22725
- Thanks for LABS: US Department of Energy, NA-50, ASC-PEM

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